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ANALYSIS OF FOREIGN OBJECT IMPACT ON AIRCRAFT

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ABSTRACT

Birds are threat to aircraft, not all but almost. Some birds lead to serious accidents involving aircraft of classes. Bird strike damages a lot, economically and physically. The lives of the crew, passengers are at risk ultimately. Since 1988, over 200 people have been killed worldwide as a result of encounters with airborne animals usually birds.

A homogenous bird model with a simplified geometrical shape is modelled. The reliability and authenticity of the bird model is validated by comparing the numerical result with experimental results of a real bird of similar mass impacting normally at an impact velocity of 116m/s onto a flat rigid panel of composite glass (windshield) and aluminium/Titanium (panel). The obtained numerical results are found to be comparable in terms of plastic strain, Von Mises and the bird trajectory. The modelling of bird strike using the Lagrangian Formulation is then investigated by modelling impact on an aluminium/Titanium body panel and on the Wind Shield of an Aircraft.

The numerical results obtained from the formulation shows close conformity implying their appropriateness as alternative in the simulation of bird strike. Analysis is made based on the obtained numerical results. LS-Dyna and Ansys is used for impact analysis. However software like Hyper-mesh was used for pre-processing (Mesh) and CATIA was used for detailed modelling of the parts for analysis. The result strictly portrays the structural strength or the failure against the impact by a high momentum body obstruction in the flight. Suggestion is provided on the basis of analysis study for wind chill.

KEYWORDS: ***Numerical Results, Software like Hyper-Mesh, Pre-Processing (Mesh) and CATIA***

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Original Article

INTRODUCTION

Background

When a bird and a plane collide in midair, it's the bird that comes off second best.

In the past 100 years bird strike has cost the aviation industry billions of dollars and led to more than 200 deaths. Damage from bird strikes is estimated at 550,000 hours of aircraft down time/year, which equates to an annual cost of $625 million. [Source: http://www.tripbase.com]

During its life cycle an aircraft flies on the risk of impacting foreign objects. According to the aeronautical specifications, with the term bird-strike we mean the collision between a bird and an aircraft-facing component, which includes windshield, nacelles, and wing leading edge and compressor blade. The take-off and landing stages are the most frequent situations vulnerable to these accidents and also depends on the bird activities, geographical characteristics. In recent years the severity and importance of the bird strike has grown because of the remarkable increase of the air traffic and airplane performances in term of velocity, followed by an increment of energy density and impulsive loads during the impact.

Bird strikes have been a concern to both civil and military aircrafts.

Bird strike [**Source:** www.abc.net.au]

Figure 1

Wing/Rotor and the Nose/Radome/Fuselage being the parts that are often susceptible to these impacts. Therefore it is important to ensure that the structural parts are damage tolerant to these high velocity impacts or at least guarantee the safe landing of the aircraft after the strike.

Aircraft engines and windshields are tested through simulated bird strikes whereby dead chickens are fired from a cannon at varying weights and speeds.

Federal Aviation Administration (FAA) and European Aviation Safety Agency (EASA) list regulations establish certification standards, which include verifying the structural integrity of airframes and engines. These empirical verifications, which result in the damage of prototypes and the biological hazard of using real birds, can be costly and time consuming. The use of computer simulation to simulate the bird impact on new structural components serves as a powerful tool for the development of new components by minimizing the number of empirical testing. It allows the impact response of different structural and material parameters to be studied before the actual fabrication of the prototypes, thus reducing time and cost incurred in empirical testing. The finite element simulation was performed using LS-Dyna and Ansys. A 4 lbs (1.82 kg), homogenous bird model with a simplified geometrical shape was modelled.

Table 1

Aircraft Component	Bird Weight	FAR Section
Windshields and Frames	4 lb	25.775 (b), 25.775 (c)
Wing Leading Edges	4 lb	25.571(e)(1)
Empennage Leading Edges	8 lb	25.631, 25.571(e)(1)
Engine – Inlet Lip	4 lb	25.571(e)(1)
Engine – Fan Integrity	4 lb	33.77, 25.571(e)(1)
Engine – Continued Operation	Up to 16 of 3 oz birds Up to 8 of 1.5 lb birds	33.77, 25.571(e)(1)

Bird Properties as per Federal Regulations ***[Source:*** *www.rolls-royce.com]*

Explicit Finite Element analysis is a numerical technique used in case of highly Nonlinear behaviour of materials with inelastic strains, high strain rates and large deformations, such as it occur during a bird strike.

For a bird strike phenomenon, to obtain a good prediction of the impact loads and damage of an aircraft structure under impact loading, it is essential to adopt a realistic material model for a bird and its associated material and geometrical parameters.

To achieve an accurate bird model an explicit code, like LSTC/LS-Dyna, offers different approaches to modeling:

- **Arbitrary LaGrange Eulerian (ALE) Approach.**
- **LaGrange Approach.**
- **Smoothed Particle Hydrodynamics (SPH) Approach.**

Table 2

Approach	Advantages	Disadvantages
Lagrangian	Low CPU time, wide choice of the contact algorithms	Mesh distortion, eroding nodes moves independently from each other
SPH	Mesh-free method, no mesh distortion	Impossible to describe the contact between the bird and blade's edge
ALE	No mesh distortion	High CPU time, requires high number of ALE cells

Different Approach for Analysis

The reliability of the bird parameters was validated by simulating collision of the Lagrangian bird model at 90^{o} onto a flat rigid panel (glass and aluminum) at an impact velocity of 116m/s and comparing with reported experimental data.

SOFTWARE

LS-Dyna

It is a combined Implicit/Explicit software for highly nonlinear transient problems enabling the solution of coupled multi-physics and multi-stage problems. It was developed by Livermore Software Technology Corporation (LSTC), the Multicore processors and fully automated contact analysis and wide range of material models enable users worldwide to solve complex real world problems.

The calculation of many complexes, real world problems, its origins and core-competency laid in highly nonlinear transient dynamic **finite element analysis (FEA)** using explicit time integration.

LS-Dyna consists of a single executable file and is entirely command line driven. Therefore all that is required to run LS-Dyna is a command shell, the executable, an input file, and enough free disk space to run the calculation.

LS-Dyna is being used by Aerospace, Automobile, construction, and Military industries.

Typical Usage:

Nonlinear Dynamics means at least one of the following complications:

- Changing boundary conditions (such as contact between parts that changes over time)

- Large deformations (for example the crumpling of sheet metal parts)
- Nonlinear materials that do not exhibit ideally elastic behavior (for example thermoplastic polymers)

Transient Dynamic means analyzing high speed, short duration events where inertial forces are important. Typical uses include

- Automotive crash (deformation of chassis, airbag inflation, seatbelt tensioning)
- Explosions (underwater mines, shaped charges)
- Manufacturing (sheet metal stamping)

In studying the parameters for the bird strike on windshield and on the aluminum panels the software provides the actual real-time scenario to procure the precise solution.

Ansys

Ansys offers a comprehensive range of engineering simulation solution sets providing access to virtually any field of engineering simulation that a design process requires. Companies in a wide variety of industries use Ansys software.

The tools put a virtual product through a rigorous testing procedure (such as crashing a car into a brick wall, or running for several years on a tarmac road) before it becomes a physical object.

Aerospace

- **Parker Aerospace**: Ansys was used for high-performance computing for faster simulation results.
- **Astro-botic Technology:** And Carnegie Mellon University spacecraft structural analysis for strength and stiffness.
- **Terrafugia:** Road-able aircraft for proof-of-concept testing

These set of software provide the state-of the art analysis and modeling tool, which curb all the stresses, strain, displacement and fracture in Graphical User Interface software. It is the complete package from modeling to the analysis of the modules. These are prime essential tool for Windshield and aluminum panel analysis.

Background

The studies of bird strikes can generally be classified into 2 categories namely hazard prevention and bird impact testing.

Hazard Prevention involves collecting data from cases of bird strikes on aircraft and implementing measures to prevent them through the better understanding of the nature of strikes. This includes knowing the type of birds, the location, time of the day, season of the year, etc. whereby the strike occurs.

Although measures have been implemented to prevent bird strikes from occurring, it is impossible to prevent them totally. It is therefore important to ensure that impact response on the aircraft is fully understood so as to give assurance to the pilot, passenger, etc. in cases where strikes occur. This is done through bird impact testing.

Need for Hazard Prevention [**Source:** www.heathrowairport.com]

Figure 2

Bird impact testing consists of empirical studies as well as numerical studies. Through bird impact testing, new engines and airframes are subjected to simulated and actual bird strikes. Certification of new aircraft parts is usually done empirically. These testing can be expensive and time consuming hence preliminary studies is usually done by numerical simulation before actual empirical testing.

Hazard Prevention

Collision between aircraft and bird has been a concern because they threaten the safety of the people on board the aircraft, results in costly repairs and in the case of commercial aircraft, a loss in revenue. It is a hazard that threatens to weaken the public confidences towards the aviation industries. International committees such as the International bird strike committee, the U.S and Italian bird strike committee, etc. have been formed to counter the threat posed by bird strikes, to better understand the nature of strikes and to implement measures to prevent such strikes.

Since 1988, many people have been killed worldwide as a result of bird strikes. Bird strikes are not rare cases as most people professed. In the United States alone 52,493 strikes have been reported from 1990 to 2003. Within this 14 years period, 244,510 hours of aircraft down time and $163.51 million were loss. Analysis of strike reports has shown that the number of reported strikes constitutes only about 20% of the total number that truly occurs which means that the amount of monetary losses can be much more than what is actually estimated. Bird strike is therefore a much more serious problem than what most people perceived especially when the numbers of aircraft are increasing every year and becoming faster and quieter.

Generally, the number of reported strike decreases with altitude. Jetliners normally cruise at about 35,000 feet (10000m) at speeds over 500 miles per hour (224 m/s). They usually take off and land at a speed of up to 235 miles per hour (105 m/s). Reported studies show that it is near the airport where aircraft are most vulnerable to bird strikes. Birds are

attracted to airport due to the presence of shelter, feeding, drinking and bathing areas. In United States, 92% of the strikes occur at below 3000 feet (920m) and a total of 97% of the reported strikes occur during the taking off and landing phase of the aircraft.

Due to the higher proportion of strikes at take-off and landing, the impact response on aircraft components, windshield, engine compressor, fan blades, etc. is calculated experimentally and numerically. The Federal Aviation Administration (FAA) and the European Joint Aviation Authority certify airframes and engines airworthiness standard.

Due to the large variety of birds, which vary in size and weight, that are involve in bird strikes, it is not possible to ensure the airworthiness of an airframe or engine for any particular type of bird.

An optimum standard is therefore chosen after weighing the various factors, which includes the probability and severity of strikes, the aircraft-operating environment, as well as the economic cost, involve in implementing the standard. One of the requirements for airframes by the FAA for transport category aircraft requires that the aircraft be able to successfully complete a flight after impact with a 4lb (1.82kg) bird. The use of bird weighing 1.82kg is therefore used for impact testing in a number of experimental and numerical studies.

Modeling Methodologies

The finite element analysis of the bird strike is performed using Ls- Dyna whereby its main solution methodology is based on explicit time integration. Explicit methods are more efficient compared to implicit method for fast phenomenon such as impact. The keyword format is used for the input deck. The finite element mesh of the bird is generated using Hyper-Mesh. The parameters discussed in this section apply byLagranngIann.

The extent of damage that results from bird impact is governed by several parameters. The reasons for choosing the various parameters are discussed subsequently. It should be noted however that the choice of the parameters is dependent on the availability of experimental results with similar bird parameters to compare against.

Momentum

The initial momentum of the bird along trajectory is simply **m.v**, where m is the mass of the bird and v is the initial impact velocity of the bird. Since the bird has only radial velocity then the momentum of the bird along trajectory after impact is zero.

Therefore, the momentum transferred to the target during the impact is simply equal to m.v extending this concept to oblique impacts, only the component of momentum normal to the impact surface is transferred to the target and the momentum transfer is given by:

$$\mathbf{I} = m.v \sin \theta$$

Where, θ is the angle between the trajectory and surface of the target. The equation describes the impulse imposed onto a rigid target during impact when the bird is assumed to be a fluid body.

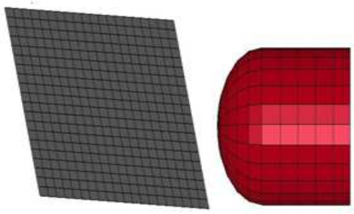


Figure 3

Bird and Panel

A fluid like hydrodynamic is chosen for the bird. While analysis of this bird computer aided prototype the material used was MAT_NULL is applied as it considered the entire gelatin like material and properties. The fluid like hydrodynamic response of the bird material model is defined by card ***MAT_NULL** and equation of state by card ***EOS_LINEAR_POLYNOMIAL** in LS- Dyna.

Model Verificaiton

The reliability of the various parameters discussed earlier is first validated by simulating bird impact at a velocity of 116m/s on a rigid, flat panel using a LaGrange bird model. A rigid target instead of a deformable one is chosen for the validation so that the bird parameters can be determined independent of the constitutive response of the target. A normal impact and a flat windshield are conditioned.

The finite element mesh of the rigid target is created using Hyper-mesh evenly distributed shell elements. Shell element is used since the thickness of the plate is much smaller compared to its other dimensions shows the geometry of the rigid plate. Constraining the node's rotational and translational degree of freedoms at all the edge of the plate sets the boundary conditions of the windshield target. Cards of different material define the material property of the rigid Plexi-glass plate, as it comprises of four different layers of composite laminates.

In the LaGrange formulation, the material is bounded to the mesh; the mesh followed the distortion and movement of the material. Due to symmetry, the LaGrange bird model can be represented using a quarter models. Figure shows the initial position of the LaGrange bird model and the rigid target. The bird model is position as close to the target as possible. For an impact velocity of 116m/s, the time taken for the whole bird to fully impact the rigid plate is 2.05ms. A termination time of **0.005s** is set in card ***CONTROL_TERMINATION**.

The coupling between the LaGrange bird and the target is represented using an Eroding Node to Surface Contact algorithm defined by the Card

ERODING_NODE_TO_SURFACE_CONTACT. Using this contact card, the coupling between the bird and target is based on a penalty method whereby the amount of penetration between the slave and master side is governed by penalty stiffness. The required penalty stiffness can be calculated using the relationship between the bulk modulus between the slave and master part. Incorrect penalty stiffness can lead to excessive penetration of the bird model into the rigid plate, which eventually results in numerical errors.

PROCEDURE FOR ANALYSIS (I)

Geometry Modelling

The model was designed in CATIA V5 R18 where a square plate and bird as in shape of hemispherical head and cylindrical aft. File Extension created was. Iges**.**

Finite Element Analysis

The finite element method (FEM) consists of the following five steps:

- **Preprocessing:** subdividing the problem domain into finite elements.
    - **Element Formulation:** development of equations for elements.
    - **Assembly:** obtaining the equations of the entire system from the equations of individual elements.
- **Solve:** Solving the equations.
- **Post-Processing:** determining quantities of interest, such as stresses and strains, and obtaining visualizations of the response

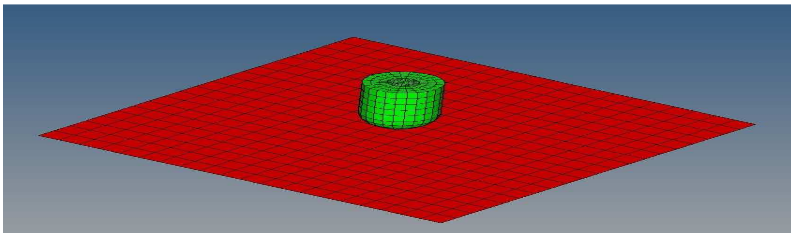


Figure 4

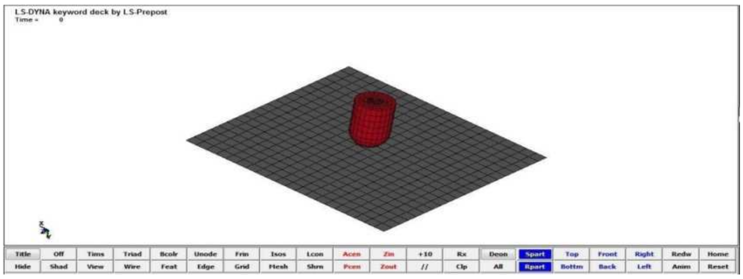


Figure 5

PREPROCESSING (MESH)

The model is divided in to small units (elements) which will help in analysing the impact at each individual area. Hexagonal mesh is done on the plate whereas solid mesh on the bird model.

PROPERTIES ASSIGNMENT

After improvised FEM, properties were assigned after importing the pre-processed geometry from hyper-mesh where all the nodes were assigned for analysis. It was then saved in **.k, which** is enabled to execute in LS-Dyna Pre-post. Material used: A) **Composite Windshield** 1. **MAT_ NULL** (Bird) 2. Combination of

- MAT**_VISCOELASTIC** (Acrylic Layer) b) **MAT_KINEMATIC_PLASTIC** (PVB Layer)

- **Aluminum panel MAT_ELASTIC** card defines the properties of deformable aluminum.

Simulation

As all the control cards are well in place, it is the time to run the model which provides the analysis report in. d3plot file which are imported in LS-prepost software to simulate.

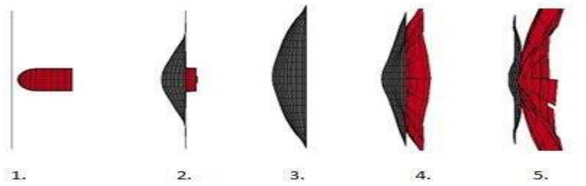


Figure 6

Finite Element Analysis

The same model is made with the exact dimensions of aluminum plate and bird, then Ansys 14.0 implicate the meshing as per plate which undergoes shell mesh whereas the bird underwent hexagonal mesh.

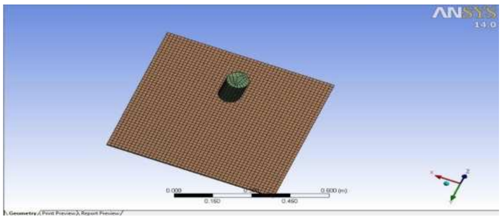


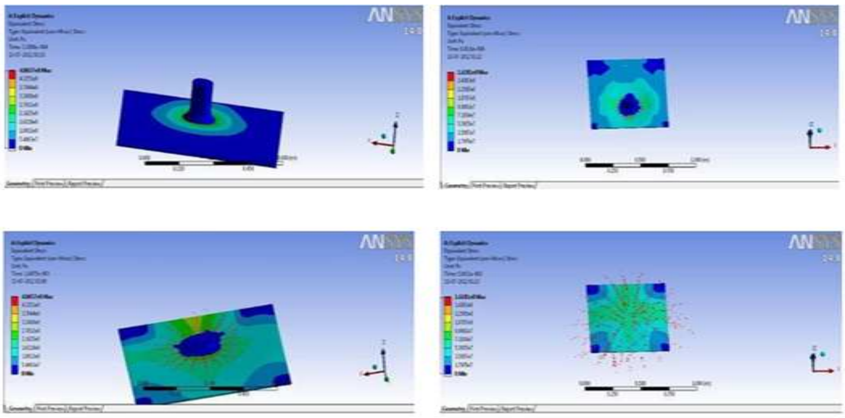
Figure 7

Control Cards & Material Assignment

When model is meshed, properties and constraints are applied to it. After which the control cards are applied which are way too different than LS-Dyna procedure. Ansys 14.0 are User-friendlier which help the model to provide easy termination and initiation controls. Material assigned to Plate was Aluminum and Bird was assigned to hydrodynamic properties.

Simulation

It is the final step of the software where the results and the performance of the material are animated and calculations are done consecutively. The results can be saved in any extension as per the user requirement. The graphs were generated through operating **results** option.



Simulation in Ansys [**Source:** Ansys 14.0]

Figure 8

RESULTS

Composite Plate

LS-Dyna Post Processing

D3plot file created from input deck is then executed in LS-prepost. By declaration of card *glstat and *matsum, output results are generated. The files thus loaded generates graph between the selected parameters.

Plastic Strain

The bird completely sabotaged after the impact of 116m/sec onto the windshield, which results into the bending of the plate within certain limits and avoiding cracks and its propagation to failure. The regions denoted by Red color are the maximum value attained areas. **Maximum Plastic Strain is 19.7%.**

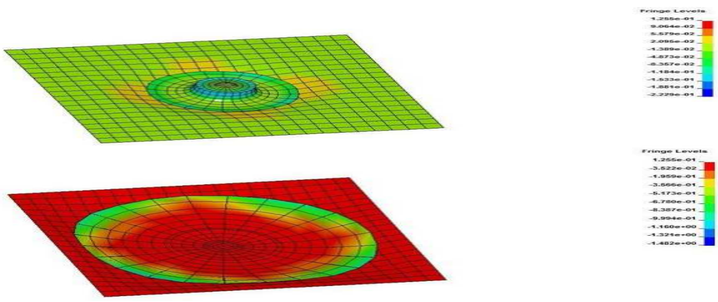


Figure 9

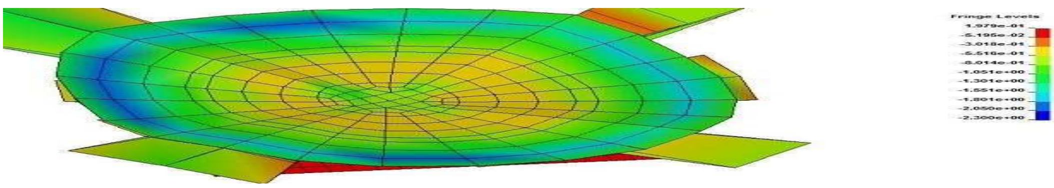


Figure 10

Von Mises Stress

Von Mises stress is used to predict yielding of materials under any loading condition from results of simple

uni-axial tensile tests. The von Mises stress satisfies the property that two stress states with equal distortion energy have equal von Mises stress. During Impact the maximum stress was generated at the point of impact. If Von Mises stress increases the ultimate tensile strength then it would result in failure of the component. After the impact, maximum stress exponentially increases on the fixed ends providing rigid support to the component. As per FAA regulations the fixture connection should be certified for impact loads. **Maximum Von Mises Stress induced is 8.16e7 N/.**

The time-history of the internal energy for each layers of the laminated glass is reported. The outer glass, on which the bird impacts directly, is the ply that absorbs the bigger amount of the bird impact energy, but contrarily to what you might think, after that the two PVB layers turn out to be very efficient about the energy absorbing, because of their plastic behavior.

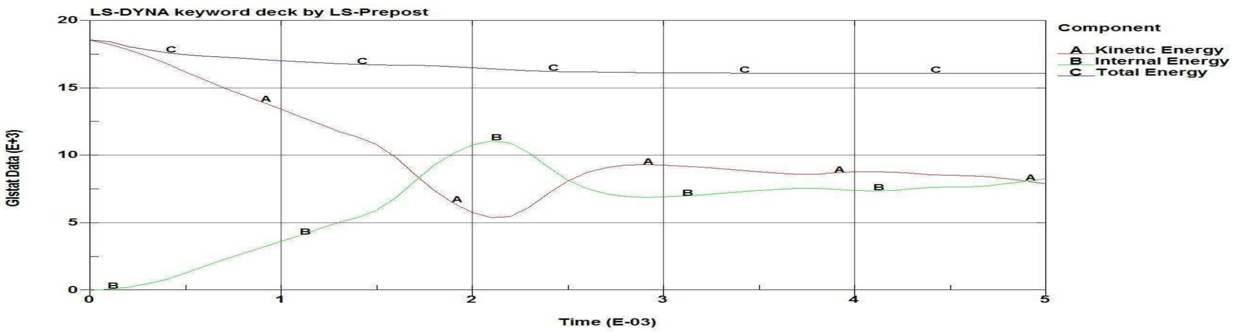


Figure 11

This graph represents the energies of both the components as well as in combination. The **ASCII** control card is selected in which **glstat*** option creates a **glstat*** file. When **glstat*** is loaded, the different parameters to be represented in the graph are selected thus creating a plot.

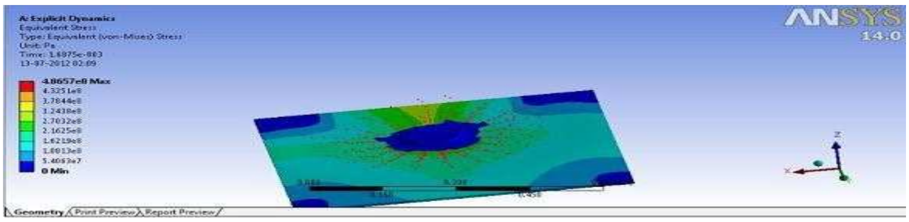


Figure 12

Total Deformation

The total permanent set in plate after the impact is called as total deformation,which is lower than the ultimate deflection before breaking.

Total Deformation Plot

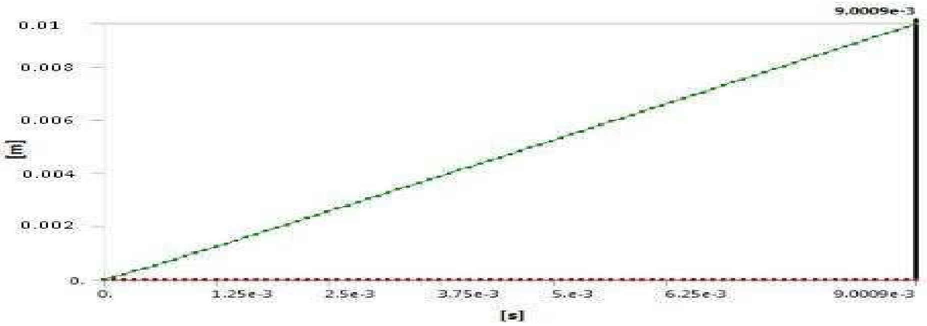


Figure 13

CONCLUSIONS

Among the three approaches namely LaGrange, SPH and ALE. LaGrange was the most appropriate approach as it provides wide choices of contact algorithms and low CPU time. Using LSTC/LS –Dyna and Ansys explicit solver, performed numerical simulation. A preliminary validation of the bird strike methodology was achieved through a simulation on a simplified, but representative, windshield structure and Aircraft panel.

This research work was the development a scientific and methodological approach to the study of the bird strike problem for the design, verification, and optimization of a bird-proof windshield of an airplane.

RECOMMENDATIONS

- **Composite Windshield:** The windshield of aircraft comprising of four layers of different laminates which can absorb more impact energy induced during bird- strike than the conventional glass shield. To decrease the displacement observed in the analysis, thickness of the composite windshield should be increased.
- **Aluminum Panel:** As per the strike analysis, the margin of safety came out to be 70 times safer than the induced stress. Hence, the aluminum panel thickness can be reduced which can increase the cost-effectiveness by saving material.

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